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DRY BEAN GENOTYPES EVALUATION FOR GROWTH, YIELD COMPONENTS AND PHOSPHORUS USE EFFICIENCY

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DRY BEAN GENOTYPES EVALUATION FOR GROWTH, YIELD COMPONENTS AND PHOSPHORUS USE EFFICIENCY

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□ *Dry bean along with rice is a staple food for the population of South America. In this tropical region beans are grown on Oxisols and phosphorus (P) is one of the most yield limiting factors for dry bean production on these soils. A greenhouse experiment was conducted to evaluate P use efficiency in 20 elite dry bean genotypes grown at deficient (25 mg P kg^{-1} soil) and sufficient (200 mg P kg^{-1}) levels of soil P. Grain yields and yield components were significantly increased with P fertilization and, interspecific genotype differences were observed for yield and yield components. The grain yield efficiency index (GYEI) was having highly significant quadratic association with grain yield. Based on GYEI most P use efficient genotypes were CNFP 8000, CNFP 10035, CNFP10104, CNFC 10410, CNFC 9461, CNFC 10467, CNFP 10109 and CNFP 10076 and most inefficient genotypes were CNFC 10438, CNFP 10120, CNFP 10103, and CNFC 10444. Shoot dry weight, number of pods per plant, 100-grain weights and number of seeds per pod was having significant positive association with grain yield. Hence, grain yield of dry bean can be improved with the improvement of these plant traits by adopting appropriate management practices. Soil pH, extractable P and calcium (Ca) saturation were significantly influenced by P treatments. Based on regression equation, optimum pH value in water was 6.6, optimum P in Mehlich 1 extraction solution was 36 mg kg^{-1} and optimum Ca saturation value was 37% for dry maximum bean yield.*

Keywords: grain yield, *Phaseolus vulgaris* L., P-use efficiency index, grain harvest index

INTRODUCTION

Dry bean is also known as common bean, pinto bean, snap bean, field bean, French bean, navy bean or kidney bean is grown globally in all continents with exception of Antarctica (Gepts, 1998). It was originated

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and domesticated in Latin America (Gepts and Debouck, 1991). It is an important grain legume crop and supply a large part of the daily protein requirement of the people of South America, the Caribbean, Africa and Asia (Fageria et al., 1997; Fageria, 2002). In developing countries, dry bean is mainly consumed as a dry seed. In developed countries, it is mainly consumed as fresh pods and as frozen vegetables. In the South America, dry bean is daily consumed along with rice by all section of population. Seeds of dry bean have about 22% protein and dry bean is a principal source of protein for more than 500 million people in Latin America and Africa (Fageria, 2002).

Grain yields of this legume are quiet low in developing as well as developed countries. In most of the developing countries, average grain yields of dry bean are less than 1 Mg ha^{-1}, whereas in developed countries grain yield average less than 1.5 Mg ha^{-1} (Fageria et al., 1997). Many of the biotic and abiotic stresses are the major contributors for low grain yields (Fageria and Santos, 2008). In South America, drought, diseases, and insects are the major yield limiting factors for dry beans (Fageria, 2002). In Brazil, dry bean is mostly grown in the cerrado region and soils of this region are acidic and having low native fertility (Fageria, 2002). Phosphorus (P) is one of the most yield limiting factors in soils of corrode (Fageria and Baligar, 1997). Intra- and inter specific differences in growth, grain yield, and nutrient use efficiency including dry bean have been reported in many plant species (Gerloff and Gabelman, 1983; Vose, 1984; Baligar and Fageria, 1997, 1999; Baligar et al., 2001; Fageria, 2009). Genetic and physiological components of plants have profound effects on nutrient use efficiency in plants (Clark and Duncan, 1991; Gerloff and Gabelman, 1983; Vose, 1984; Baligar et al., 2001; Fageria, 2009). Differences in P use efficiency are related to their ability to grow in soils with low P and this is attributed to their unique root system morphology, root hair density, and root exudates (Baligar et al., 2001). Nutrient use efficiency differences in crop genotypes are related to differences in absorption, translocation, shoot demand, dry matter production per unit of nutrient absorbed, and environmental interactions (Baligar et al., 2001; Clark and Duncan, 1991; Gerloff and Gableman, 1983; Vose, 1984).

Identification of dry bean genotypes efficient in P utilization will be useful in developing a breeding program to produce superior P use efficient cultivars for low P soils. The development of new cultivars with higher P use efficiency, coupled with best management practices will help to develop sustainable agricultural systems to resource poor farmers of the tropical region. Planting genotypes with high P use efficiency is an important strategy in improving dry bean yields and further utilization of P efficient cultivars will reduce the cost of production by lowering P fertilizer inputs. It is also an important management practice for sustainable crop production in low fertility soils and further reducing environmental pollution.

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Existence of inter-specific genotype differences in dry bean for yield components such as grain number per pod, number of seeds per pod and weight of 100 grains have been reported and these components have positive significant relation to grain yield (Tanaka and Fujita, 1979; Fageria et al., 2006, 2007; Fageria and Santos, 2008, Wallace et al., 1972). These yield components are under genetic control and are influenced by environmental variables and abiotic and biotic stresses (Tanaka and Fujita, 1979; Fageria et al., 2006; Wallace et al., 1972). Grain yield harvest index (GHI) and grain yield efficient index (GYEI) in crop genotypes are in influenced by nature of genotype and environmental factors (Fageria and Santos, 2008) and appears to be a good index in differentiating dry bean genotypes for their ability to produce grain yield and indicators of their efficiency for P use at differing soil P levels (Fageria et al., 1997, 2006; Fageria and Santos, 2008; Wallace et al., 1972) The GYEI has been successfully used to differentiate genotypes into efficient and inefficient nutrient [nitrogen (N), P, potassium (K), micronutrients] utilizations in rice (Fageria and Barbosa Filho, 1981; Fageria, 1989; Fageria and Baligar, 1993). The objective of this study was to evaluate inter-specific differences in a promising dry bean genotypes used in a breeding programs for growth, yield components, grain harvest index and P-use efficiency at insufficient and sufficient soil P levels.

MATERIALS AND METHODS

Soil Properties and Levels of Nutrient Input

The experiment was conducted in a greenhouse at the National Rice and Bean Research Center of Embrapa, Brazil. The soil used in the experiment was an Oxisol with following chemical and physical properties before applying P treatments: pH in H_2O 5.2, calcium (Ca) 0.6 $cmol_c$ kg^{-1}, magnesium (Mg) 0.3 $cmol_c$ kg^{-1}, aluminum (Al) 0.2 $cmol_c$ kg^{-1}, P 1.2 mg kg^{-1}, K 48 mg kg^{-1}, copper (Cu) 1.9 mg kg^{-1}, zinc (Zn) 0.6 mg kg^{-1}, iron (Fe) 36 mg kg^{-1}, manganese (Mn) 11 mg kg^{-1}, and organic matter 2.0 g kg^{-1}, clay 707 g kg^{-1}, silt 80 g kg^{-1}, and sand 213 g kg^{-1}. Methodology used for soil analysis is described in Manual of Soil Analysis (EMBRAPA, 1997). Each pot of 9 kg soil received 30 g lime four weeks before sowing. The liming material used was having 27.4 9% calcium oxide (CaO), 15.2% magnesium oxide (MgO) and neutralizing power of 73%. The P treatments were applied at sowing through triple super phosphate at the rate of 25 mg P kg^{-1} as low level (in sufficiency) and 200 mg kg^{-1} of soil as high level (sufficiency). At the time of sowing basal fertilizers rates used were 200 mg N kg^{-1} of soil and 200 mg K kg^{-1} of soil. Nitrogen was applied as urea and K was applied as potassium chloride. In addition, at one week before flowering 200 mg N kg^{-1} of soil was topdressed.

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Dry Bean Genotypes and Growing Conditions

Twenty promising (elite) dry bean (*Phaseolus vulgaris*, L.) genotypes from the breeding program of National Rice and Bean Research Center of EMBRAPA were used in the experiment. These genotypes includes: CNFC 10467, CNFP 8000, CNFC 10455, CNFP 10035, CNFC 10410, CNFP 10076, CNFC 10432, CNFP 10093, CNFC 10408, CNFP 10103, CNFC 9461, CNFP 10104, CNFC 10429, CNFP 10109, CNFC 10431, CNFP 10120, CNFC 10438, CNFP 10206, CNFC 10444 and CNFC 10470.

The experiment was conducted in plastic pots with 9 kg soil in each pot. After germination, four plants were maintained in each pot. Plants were grown at field capacity moisture and every day desired amount of water was added to keep the moisture level. Plants were harvested at physiological maturity. Pods were collected from each pot and after threshing pods seeds were separated, dried, and weighed. Shoots were harvested from each pot and harvested material was washed in distilled water several times and was dried in an oven at 70°C to a constant weight to determine shoot dry weight accumulations.

Grain yield efficiency index (GYEI) was calculated to classify genotypes for their P-use efficiency as follows (Fageria et al., 1988):

GYEI = (Grain yield at low P level/average grain yield of 20 genotypes at low P level) × (grain yield at high P level/average grain yield of 20 genotypes at high P level)

Genotypes having GYEI values >1 were classified as efficient (E) P user, genotypes having GYEI values between 0.5 and 1 were classified as moderately efficient P user (ME) and those with GYEI values < 0.5 were classified as inefficient (IE) in P user. Soil samples were taken from each pot at harvest for one P efficient genotypes (CNFP 10104), three moderately P efficient genotypes (CNFC 10429, CNFC 10431 and CNFC 10470) and two P inefficient genotypes (CNFP 10103 and CNFP 10120) to determine chemical properties.

The cation exchange capacity (CEC),% base saturation, and% acidity, Ca, Mg, and K saturation were calculated with the help of following equations (Fageria et al., 2007):

CEC ($cmol_c\ kg^{-1}$) = Σ(Ca, Mg, K, H, Al), where, Ca, Mg, K, H, and Al are in $cmol_c\ kg^{-1}$.
Base saturation (%) = Σ(Ca, Mg, K)/(CEC) × 100
Acidity saturation (%) = (H + Al/CEC) × 100
Saturation of Ca, Mg, or K (%) = (Ca)/(CEC) × 100, (Mg)/(CEC) × 100, or (K)/(CEC) × 100

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Statistical Analysis

Analysis of variance was used to evaluate treatment effects, and means were compared by Turkeys test at the 5% probability level. Regression analysis was also done wherever it was necessary. Appropriate regression model was selected on the basis of R^2.

RESULTS AND DISCUSSION

Grain Yield and Growth

Significant interaction was observed between soil P levels X genotype for grain yield and shoot dry weight, indicating different response magnitude of genotypes for soil P levels (Table 1) Grain yield of 20 genotypes varied from 0.63 g plant^{-1} produced by genotype CNFP 10103 to 3.70 g plant^{-1} produced by genotype CNFP 8000, with an average grain yield of 1.92 g plant^{-1} at 25 mg P kg^{-1} of soil. Similarly, grain yield at higher P level (200 mg P kg^{-1})

TABLE 1 Grain yield and shoot dry weight of 20 dry bean genotypes at two soil P levels

	Grain yield (g plant^{-1})		Shoot dry weight (g plant^{-1})	
Genotype	25 mg P kg^{-1}	200 mg P kg^{-1}	25 mg P kg^{-1}	200 mg P kg^{-1}
CNFC 10467	2.69abc	6.70abc	2.31ab	2.96c
CNFP 8000	3.70a	8.29ab	2.36ab	4.01bc
CNFC 10455	1.29abc	6.43abc	2.14ab	6.61abc
CNFP 10035	3.12ab	9.49a	1.62abc	5.75bc
CNFC 10410	3.11ab	9.11a	1.34abc	5.29abc
CNFP 10076	2.38abc	7.53abc	1.98ab	6.73abc
CNFC 10432	1.64abc	8.62ab	1.31abc	4.37bc
CNFP 10093	1.17bc	8.61ab	0.91bc	5.28bc
CNFC 10408	1.83abc	7.47abc	1.45abc	6.21abc
CNFP 10103	0.63c	7.89abc	1.83abc	5.96bc
CNFC 9461	2.05abc	9.23a	1.40abc	5.03bc
CNFP 10104	2.74abc	10.18a	1.89abc	6.78abc
CNFC 10429	1.37abc	9.92a	1.61abc	4.51bc
CNFP 10109	2.18abc	8.94a	1.60abc	4.97bc
CNFC 10431	1.79abc	7.74abc	1.98ab	7.10abc
CNFP 10120	1.34abc	3.67c	1.58abc	10.79a
CNFC 10438	0.89bc	4.40bc	0.33c	3.12c
CNFP 10206	1.32abc	9.03a	0.92bc	5.29bc
CNFC 10444	0.92bc	6.97abc	2.49a	5.01bc
CNFC 10470	2.22abc	5.89abc	1.36abc	8.24ab
Average	1.92	7.81	1.62	5.70
F-test				
P level (P)	**		**	
Genotype (G)	**		**	
P × G	**		**	

**Significant at the 1% probability level. Means in the same column followed by the same letter are not significantly different at the 5% probability level by Turkeys test.

varied from 3.67 g plant^{-1} produced by genotype CNFP 10120 to 10.18 g plant^{-1} produced by genotype CNFP 10104, with an average grain yield of 7.81 g plant^{-1}. Overall, increase in grain yield was 307% with increase in soil P levels from 25 mg P kg^{-1} of soil to 200 mg P kg^{-1} of soil. Fageria et al. (1997) and Fageria and Baligar (1997) reported the increase of grain yield in dry bean with the addition of P in Brazilian Oxisols. These authors reported that response of annual crops to addition of P in Oxisols is associated with low natural level of soil P and higher P immobilization capacity of these soils. The high P immobilization capacity of these soils is related to clay and Fe and Al contents (Mokwunye and Chien, 1980; Van Riemsdijk et al., 1984). Higgs et al. (2000) also reported that 30 to 50% of increase in world food grain since the 1950s are attributable to fertilizer use, including P.

At low P level (25 mg P kg^{-1}), shoot dry weight of 20 genotypes varied from 0.33 g plant^{-1} produced by genotype CNFC 10438 to 2.49 g plant^{-1} produced by genotype CNFC 10444, with an average yield of 1.62 g plant^{-1}. At higher P level (200 mg P kg$^{-1)}$, shoot dry weight varied from 2.96 g plant^{-1} produced by genotype CNFC 10467 to 10.79 g plant^{-1} produced by genotype CNFP 10120, with an average shoot dry weight of 5.70 g plant^{-1}. The overall, increase in shoot dry weight was 252% at the higher soil P level compared to low soil P level. Fageria et al. (1997) and Fageria and Baligar (1997) reported significant increase in dry bean shoot dry weight with increasing soil P levels. Similarly, Fageria (1989) reported significant quadratic increase in shoot dry weight of dry bean when soil applied P rates were increased from 0 to 200 mg P kg^{-1} in Brazilian Oxisol. Significant differences in shoot dry weight of dry bean genotypes grown on Brazilian Oxisol has been reported (Fageria, 1998).

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Yield Components and Yield Associated Plant Parameters

Soil P level and genotype (Table 2) significantly affected pods per plant, seeds per pod and 100 grain weight. Interactions for soil P with genotypes had no significant effects on pods per plant and seeds per pod, indicating that magnitude of response for these two yield components did not vary with the variation in soil P levels. However, significant soil P × genotype interaction was observed for 100 grain weight, hence values of this yield component are presented at two soil P levels (Table 2). Pods per plant varied from 2.79 produced by genotype CNFC10438 to 5.75 produced by genotype CNFP 8000. Average values of pods per plant were 4.05 for 20 genotypes. The increase in pods per plant was two folds between highest and lowest pod producing genotypes. Seeds per pod varied from 3.24 (produced by genotype CNFP 10120) to 4.67 (produced by genotype CNFP 8000), with an average value of 3.99 seeds per pod for 20 genotypes. Overall genotype CNFP 8000 produced highest pods per plant and highest seed per plant. Tanaka and Fujita (1979) reported that grain number per pod varied from 3.0 to 5.4 in two

TABLE 2 Number of pods, seed per pod and 100 grain weight of 20 dry bean genotypes

			100 grain weight (g)	
Genotype	Pods plant^{-1}	Seeds pod^{-1}	25 mg P kg^{-1}	200 mg P kg^{-1}
CNFC 10467	3.79ab	4.12abc	27.94ab	26.60abcd
CNFP 8000	5.75a	4.67a	22.18b	21.41cd
CNFC 10455	3.54ab	3.31bc	29.95ab	32.68a
CNFP 10035	4.46ab	4.51ab	30.15ab	30.20ab
CNFC 10410	4.58ab	4.04abc	34.88a	30.81ab
CNFP 10076	4.50ab	3.88abc	25.13ab	27.27abcd
CNFC 10432	4.04ab	4.42abc	26.65ab	29.29ab
CNFP 10093	4.13ab	4.23abc	19.58b	27.53abcd
CNFC 10408	4.17ab	3.53abc	29.18ab	29.78ab
CNFP 10103	3.38b	3.36bc	20.12b	29.36ab
CNFC 9461	3.63ab	4.35abc	29.11ab	33.49a
CNFP 10104	4.58ab	4.28abc	27.09ab	31.26ab
CNFC 10429	4.50ab	3.98abc	28.73ab	28.79abc
CNFP 10109	4.29ab	4.36abc	27.63ab	26.92abcd
CNFC 10431	4.00ab	3.87abc	27.32ab	29.29abc
CNFP 10120	3.38b	3.24c	25.96ab	21.32cd
CNFC 10438	2.79b	4.06abc	27.40ab	20.74d
CNFP 10206	4.58ab	4.05abc	25.82ab	24.85bcd
CNFC 10444	3.58ab	3.70abc	24.29ab	26.93abcd
CNFC 10470	3.25b	3.91abc	28.31ab	28.81abc
Average	4.05	3.99	26.87	27.86
F-test				
P level (P)	**	**	**	
Genotype (G)	**	**	**	
P × G	NS	NS	**	

**, NS Significant at the 1% probability level and nonsignificant, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level by Turkeys test.

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bean cultivars and at different plant population m^{-2}. Fageria et al. (2006) stated that pods per plant and seeds per pods in legumes are genetically controlled and difference existed among genotypes for these two traits. Wallace et al. (1972) also reported that genotypes differ significantly in the physiological processes that determine yield. These authors further reported that identification of these physiological components of yield and their genetic controls should make it possible to plan crosses to maximize segregation of genotypes possessing the physiological complementation and balance required for high yield, thereby leading to more rapid and predictable yield improvement.

At low soil P level, the 100 grain weight varied from 19.58 g (produced by genotype CNFP 10093) to 34.88 g (produced by genotype CNFC 10410), with an average value of 26.87 g. At high soil P level, 100 grain weight varied from 20.74 g (produced by genotype CNFC 10438) to 33.49 g (produced by genotype CNFC 9461), with an average value of 27.86 g. The variations in 100 grain weight in dry bean genotypes has been reported (Fageria, 2009).

TABLE 3 Grain harvest index (GHI) of 20 dry bean genotypes at two soil P levels

	GHI	
Genotype	25 mg P kg^{-1}	200 mg P kg^{-1}
CNFC 10467	0.55abc	0.70a
CNFP 8000	0.62a	0.69a
CNFC 10455	0.48abc	0.49bc
CNFP 10035	0.65a	0.63ab
CNFC 10410	0.70a	0.63ab
CNFP 10076	0.53abc	0.53abc
CNFC 10432	0.51abc	0.66ab
CNFP 10093	0.56ab	0.62ab
CNFC 10408	0.54abc	0.55abc
CNFP 10103	0.26c	0.57abc
CNFC 9461	0.55abc	0.65ab
CNFP 10104	0.55abc	0.60abc
CNFC 10429	0.47abc	0.69ab
CNFP 10109	0.58a	0.64ab
CNFC 10431	0.46abc	0.52abc
CNFP 10120	0.46abc	0.26d
CNFC 10438	0.73a	0.59abc
CNFP 10206	0.59a	0.64ab
CNFC 10444	0.27bc	0.59abc
CNFC 10470	0.62a	0.42cd
Average	0.53	0.58
F-test		
P level (P)	**	
Genotype (G)	**	
P × G	**	

**Significant at the 1% probability level. Means in the same column followed by the same letter are not significantly different at the 5% probability level by Turkeys test.

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The increase in 100 grain weight at higher soil P was about 4% compared to low soil P levels.

The grain harvest index (GHI) was significantly influenced by soil P levels, genotype, and soil P × genotypes interaction (Table 3). The GHI values varied from 0.26 for genotype CNFP 10103 to 0.73 for genotype CNFC 10438, with an average value of 0.53 at low soil P level. At high soil P level, the GHI values varied from 0.26 for genotype CNFP 10120 to 0.70 for genotype CNFC 10467, with an average value of 0.58. Overall, increase in GHI was about 9% at high soil P level compared to low soil P level. The GHI varies with the crop genotypes and it is also influenced by environmental factors (Wallace et al., 1972). Variation in GHI of dry bean genotypes grown on Brazilian Oxisols has been reported (Fageria and Santos, 2008).

Root Growth

In six selected genotypes, soil P levels, genotypes and soil P × genotype interactions (Table 4) significantly influenced root dry weight. The

TABLE 4 Root dry weight of 6 dry bean genotypes at two P levels

	Root dry weight (g plant^{-1})	
Genotype	25 mg P kg^{-1}	200 mg P kg^{-1}
CNFP 10103	0.54a	1.63ab
CNFP 10104	0.68a	1.87ab
CNFC 10429	0.61a	1.01b
CNFC 10431	0.79a	1.79ab
CNFP 10120	0.59a	2.26a
CNFC 10470	0.49a	1.34ab
Average	0.62	1.65
F-test		
P level (P)	**	
Genotype (G)	**	
P × G	*	

*,**Significant at the 5% and 1% probability levels, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level by Tukey's test.

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significant P × G interaction clearly indicates that, genotypes produced different root dry weight at two soil P levels. Root dry weight varied from 0.49 to 0.79 g plant^{-1} at the low soil P level and 1.01 to 2.26 g plant^{-1} at the high soil P level. The root weight increased by 73% by increasing soil P from low to high. At low soil P level, genotypes CNFC 10431 produced highest root dry weight where as at high soil P level genotype CNFC 10120 produced maximum root dry weight. Inter- and intra-species differences in root dry matter accumulations have been well documented and this root parameter is modified by environmental factors (Baligar et al., 1998; Fageria et al., 2006). Baligar et al. (1998) also reported that dry root weight of dry bean s increased significantly and quadratically with increasing P rate in a Brazilian Oxisol.

Interrelationships between Yield Components and Associated Plant Parameters with Grain Yield

Grain yield was significantly and quadratically increased with increasing shoot dry weight (Table 5). Based on regression equation, maximum grain yield was obtained with 3.9 g shoot dry weight. Shoot dry weight contributed 24% variation in grain yield of dry bean. Fageria (1989) reported that at different growth stages dry bean showed a highly significant correlation between grain yield and shoot dry weight. Similarly, in field experiment, Fageria et al. (2004) reported significant quadratic fashion increase in dry bean grain yield.

Pods per plant, grain per pod and 100 grain weight increased dry bean grain yield significantly and linearly (Table 5). The variability in grain yield was 63% due to variation in pods per plant, 25% variation due to variation in

TABLE 5 Relationship between yield components and grain yield of 20 dry bean genotypes. Values are across two soil P levels (n = 60)

Variable	Regression equation	R^2
Shoot dry weight (X) vs grain yield (Y)	$Y = 0.8289 + 2.2438X - 0.2856\times^2$	0.2441**
Pods per plant (X) vs grain yield (Y)	$Y = 0.1274 + 1.1697X$	0.6352**
Grain per pod (X) vs grain yield (Y)	$Y = -0.1486 + 1.2547X$	0.2480**
100 grain weight (X) vs grain yield (Y)	$Y = 1.3379 + 0.1299X$	0.0973*
Grain harvest index (X) vs grain yield (Y)	$Y = -7.7229 + 40.4721X - 31.0884X^2$	0.3862**

*, **Significant at the 5% and 1% probability levels, respectively.

grain per pod and about 1% variation in grain yield due to variation in 100 grain weight. Hence, pods per plant were most influencing yield components in determining grain yield, followed by grain per pod and 100 grain weight. Bennet et al. (1977) reported that among yield components, pods per plant has often been recommended as an indirect selection criterion for increasing yield, primarily because of its higher and more consistent correlation with yield. Similarly, Wallace et al. (1972) also reported that the grain yield was highly correlated with the pod number in dry bean. Pods per plant are genetically controlled and also influenced by environmental factors (Wallace et al., 1972; Fageria et al. 2007). Similarly, Number of grain per pod and weight of hundred grains are important yield components (Fageria and Santos, 2008). These traits are strongly under genetic control. However, both of these traits are also influenced by environmental conditions (Tanaka and Fujita, 1979).

Grain harvest index was having significant quadratic association with grain yield (Table 5). The variation in grain yield due to variation in GHI was about 39%. Gifford and Evans (1981) reported that the improvement of yield potential in crops has come largely from increase in the partitioning of assimilates into the harvested organs. Sinclair (1998) reported that the GHI is an important trait associated with the dramatic increases in crop yields that have occurred in the twentieth century. Similarly, Rasmusson and Gengenbach (1984) reported that part of the genetic improvement in yield of several crops is derived from a higher percentage of the biological yield being partitioned into plant parts comprising economic yield.

Classification of Genotypes for Phosphorus Use Efficiency

Grain yield efficiency index (GYEI) was having highly significant association with grain yield ($Y = 2.8171 + 2.4269X - 0.3067X^2$, $R^2 = 0.7562^{**}$). Based on GYEI, genotypes were classified as efficient; moderately efficient and inefficient P utilizers (Table 6). In this study, based on GYEI, eight genotypes (CNFC 10467, CNFP 8000, CNFP 10035, CNFC 10410, CNFP 10076, CNFC 9461, CNFP 10104, CNFP 10109) were classified as efficient P users,

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TABLE 6 Classification of dry bean genotypes to P use efficiency index based on grain yield

Genotype	P-use efficiency index	Classification[1]
CNFC 10467	1.20ab	E
CNFP 8000	2.06a	E
CNFC 10455	0.61ab	ME
CNFP 10035	1.97ab	E
CNFC 10410	1.88ab	E
CNFP 10076	1.22ab	E
CNFC 10432	0.99ab	ME
CNFP 10093	0.68ab	ME
CNFC 10408	0.88ab	ME
CNFP 10103	0.33ab	IE
CNFC 9461	1.42ab	E
CNFP 10104	1.90ab	E
CNFC 10429	0.92ab	ME
CNFP 10109	1.26ab	E
CNFC 10431	0.93ab	ME
CNFP 10120	0.32ab	IE
CNFC 10438	0.26b	IE
CNFP 10206	0.84ab	ME
CNFC 10444	0.43ab	IE
CNFC 10470	0.85ab	ME

[1]E = efficient, ME = moderately efficient, and IE = inefficient. Means in the same column followed by the same letter are not significantly different at the 5% probability level by Tukey's test.

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and eight genotypes (CNFC 10455, CNFC 10432, CNFP 10093, CNFC 10408, CNFC 10429, CNFC 10431, CNFP 10206, CNFC 10470) grouped as moderately efficient P utilizers. The remaining four genotypes (CNFP 10103, CNFP 10120, CNFC 10438, and CNFC 10444) were grouped as inefficient P utilizers. According to this classification, 40% genotypes were classified as P efficient, 40 were classified as moderately P efficient and 20% were classified as P inefficient. This means that dry bean genotypes have large variation in P use efficiency.

Difference in P-use efficiency among crop species and genotypes within species including dry bean is widely reported (Clark and Duncan, 1991; Baligar et al., 2001; Fageria et al., 2006). Baligar et al. (2001) reported that plants differ widely in their ability to grow in soils with low P, and this has been attributed to several plant traits, including morphology of root system and root hair density. Another important factors associated with plant ability to grow differently with low available soil P is the formation of root exudates that enables the plants to covert insoluble or low soluble P compounds such as Fe or Al-phosphate into available forms for plant acquisition and probably at the same time protecting the plants (roots) against Al toxicity by chelation (Fageria and Stone, 2006; Fageria et al., 2006). In addition, plants grown in low P medium secretes higher phosphatase enzymes by the roots, which enhances the P uptake. Remarkable differences in the levels of acid phosphatase (EC 3.1.3.2) secretion from roots under P deficient conditions has been observed in lupin (Tadano et al., 1993; Wasaki et al., 2003), corn (Yun and Kaeppler, 2001), chickpea (Li et al., 2004) and barley and chickpea (Gunes et al., 2007).

Soil Chemical Properties

Six genotypes were selected to determine their effects along with soil P levels on major soil chemical properties. Only pH, extractable P and Ca saturation were significantly affected by soil P treatments. Hence, values of these properties were presented (Table 7). Soil pH was significantly increased with the addition of 200 mg P kg^{-1} soil compared to 25 mg P kg^{-1} of soil. This increase in P may be associated with increase in Ca concentration at higher P addition. Because triple super phosphate was used as a P source and it contains about 13% Ca. Dry bean genotypes were also responsible for change in soil pH. For example, genotype CNFP 10103 reduced soil pH significantly compared to other five genotypes. Optimal soil pH for maximum yield of six genotypes was 6.6 calculated by regression equation (Table 7). Fageria et al. (2007) and Fageria (2006) reported optimal soil pH for dry bean grain yield is 6.7 in Brazilian Oxisol.

There was a significant increase in soil extractable P with the addition of 200 mg P kg^{-1} soil compared to 25 mg P kg^{-1} soil, as expected. The variation in grain yield was 73% due to variation in soil extractable P. Fageria and Baligar (1997) reported that P is one of most yields limiting nutrients for

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TABLE 7 Influence of P levels and genotypes on soil pH, extractable P, and Ca saturation

P level/Genotype	pH in H_2O	P (mg kg^{-1})	Ca saturation (%)
25 mg P kg^{-1}	6.0b	2.0b	29.8b
200 mg P kg^{-1}	6.2a	21.2a	32.1a
CNFP 10103	5.9b	12.7a	31.2a
CNFP 10104	6.1a	14.0a	32.3a
CNFC 10429	6.2a	9.6a	31.5a
CNFC 10431	6.1a	9.8a	30.6a
CNFP 10120	6.1a	8.6a	29.5a
CNFC 10470	6.1a	14.9a	30.7a
F-test			
P level (P)	**	**	*
Genotype (G)	*	NS	NS
P × G	NS	NS	NS

Regression analysis (n = 36)

Soil pH (X) vs. grain yield (Y) $= -282.8005 + 87.7144X - 6.6410X^2$, $R^2 = 0.2511^{**}$

Soil extractable P (X) vs. grain yield (Y) $= 0.8973 + 0.4668X - 0.0065X^2$, $R^2 = 0.7318^{**}$

Ca Saturation (X) vs. Grain yield (Y) $= -70.85 + 4.24X - 0.0579X^2$, $R^2 = 0.2862^{**}$

*, **, NS Significant at the 5% and 1% probability levels and nonsignificant, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level by Turkeys test. Values for P level and genotypes should be considered separately.

crop production in Brazilian Oxisols. Optimal soil extractable P (Mehlich 1) for maximum growth calculated by regression equation was 36 mg kg^{-1} of soil. Fageria and Carvalho (1996) reported maximum grain yield was achieved at 34 mg P kg^{-1} soil (Mehlich 1 extracting solution) in a Brazilian Oxisol in a greenhouse experiment. Calcium saturation was significantly increased with the addition of higher P level compared to low prate. This may be associated with increase in soil Ca concentration due to addition of triple super phosphate, which is about 13% Ca as discussed earlier. The Ca saturation significantly increased dry bean grain yield in a quadratic fashion. Optimal Ca saturation for grain yield was 37% calculated by regression equation. Fageria (2006) and Fageria et al. (2007) also reported significant quadratic increase in grain yield of dry bean with increasing Ca saturation in the in the Brazilian Oxisol.

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CONCLUSIONS

Dry bean is an important food legume for the world population. However, worldwide its average yields are low. The main reasons for low yields are biotic and abiotic stresses. Dry bean genotypes differ significantly in grain yield production, shoot dry matter accumulation, yield components and P-use efficiency. The difference in yield among genotypes was associated with difference in pods per plant, seeds per pod and 100 grain weight. The contribution of yield components in increasing grain yield was in the order of number of pods per plant > seeds per pod > 100 grain weight. In addition, shoot dry weight and grain harvest index (GHI) was also having significant quadratic association with grain yield. Grain yield efficiency index (GYEI) was having highly significant ($r = 0.87^{**}$) association with grain yield. Based on GYEI, the most P efficient genotype was CNFP 8000 and most P inefficient genotype was CNFC 10438. The GYEI appears to be an effective indexing tool to identify dry bean genotypes that are efficient utilizes of P. Optimal soil pH for maximum grain yield was 6.6 and optimal value of Mehlich 1 extractable soil P for the maximum grain yield was 36 mg kg^{-1} of soil. Similarly, optimal Ca saturation for the maximum grain yield was 37%.

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